Synergies between VSWIR and TIR data for the urban environment: An evaluation of the potential for the Hyperspectral Infrared Imager (HyspIRI)

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Synergies between VSWIR and TIR data for the urban environment: An evaluation of the potential for the Hyperspectral Infrared Imager (HyspIRI) Decadal Survey mission

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ABSTRACT

This study provides an introduction to the HyspIRI mission a National Research Council "Decadal Survey" mission that combines a 213 channel visible, near−infrared and shortwave infrared (VSWIR) imaging spectrometer with an 8 channel multispectral thermal infrared (TIR) instrument and evaluates some of its potential in urban science. Potential synergies between VSWIR and TIR data are explored using analogous airborne data acquired over the Santa Barbara metropolitan region in June, 2008. These data were analyzed at both their native spatial resolutions (7.5 m VSWIR and 15 m TIR), and aggregated 60 m spatial resolution similar to HyspIRI. A spectral library of dominant urban materials (e.g., grass, trees, soil, roof types, roads) was developed from field and airborne-measured spectra using Multiple-Endmember Spectral Mixture Analysis (MESMA) and used to map fractions of impervious, soil, green vegetation (GV, e.g., trees, lawn) and non-photosynthetic vegetation (NPV). Land Surface Temperature (LST) and emissivity were also retrieved from the airborne data. Co-located pixels from the VSWIR and TIR airborne data were used to generate reflectance/emissivity spectra for a subset of urban materials. MESMA was used to map GV, NPV, soil and impervious fractions at the different spatial resolutions and compare the fractional estimates across spatial scales. Important surface energy parameters, including albedo, vegetation cover fraction, broadband emissivity and surface temperature were also determined for and evaluated for 14 urban and natural land-cover classes in the region. Fractions were validated using 1 m digital photography.

Fractions for GV and NPV were highly correlated with validation fractions at all spatial scales, producing a near 1:1 relationship but with a <10% overestimate of GV from MESMA. Similar, high correlations were observed for impervious surfaces, although impervious was significantly underestimated in most urban areas and soil overestimated. Comparison of fractions across scales showed high correlation between GV and NPV at 7.5 and 60 m resolution, suggesting that HyspIRI will provide accurate measures of these two measures in urban areas. An inverse relationship between vegetation cover and LST was observed. Albedo proved to be highly variable and poorly correlated with LST. Broadband emissivity was far less variable with high emissivity surfaces (~0.95) including vegetation, water and asphalt, and low emissivity surfaces (<0.95) including selected roof types, beach sands and senesced grasslands. Residential and commercial areas showed a general pattern of increasing LST with increasing impervious fraction with the highest impervious fractions mapped in commercial areas, roads and roofs. Fine scale spatial structure in cover fractions and LST demonstrated important departures from a simple inverse relationship between GV and LST, even at 60 m. The results demonstrate the utility of HyspIRI data for urban studies and provide an insight of what will be possible on a global scale when HyspIRI data become available.

1. Introduction

The 21st century can be characterized as the first "urban century", in which a majority of people live in cities. This great urban explosion is projected to continue with the United Nations estimating global urban population to reach 81% by 2015. There are currently 21 so-called "mega-cities" with populations exceeding 10 million, and it is projected that they will significantly increase in

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Outline

- Why Urban?
- Potential HyspIRI Synergies
- Santa Barbara Study Design
- Research Results
- What’s next?
- Summary

Why Urban? (Vol 1)

- **A majority of the human population lives in urban and sub-urban areas**
  - **How does urbanization and urban composition modify urban environments and human habitat?**
  - **How might this change in a warmer world?**
    - **1995 Chicago Heat Wave (750 heat related deaths)**
    - **2003 European Heat Wave (>40,000, heat related Deaths)**
    - **2010 Great Russian Heat Wave (11,000 heat related deaths in Moscow)**

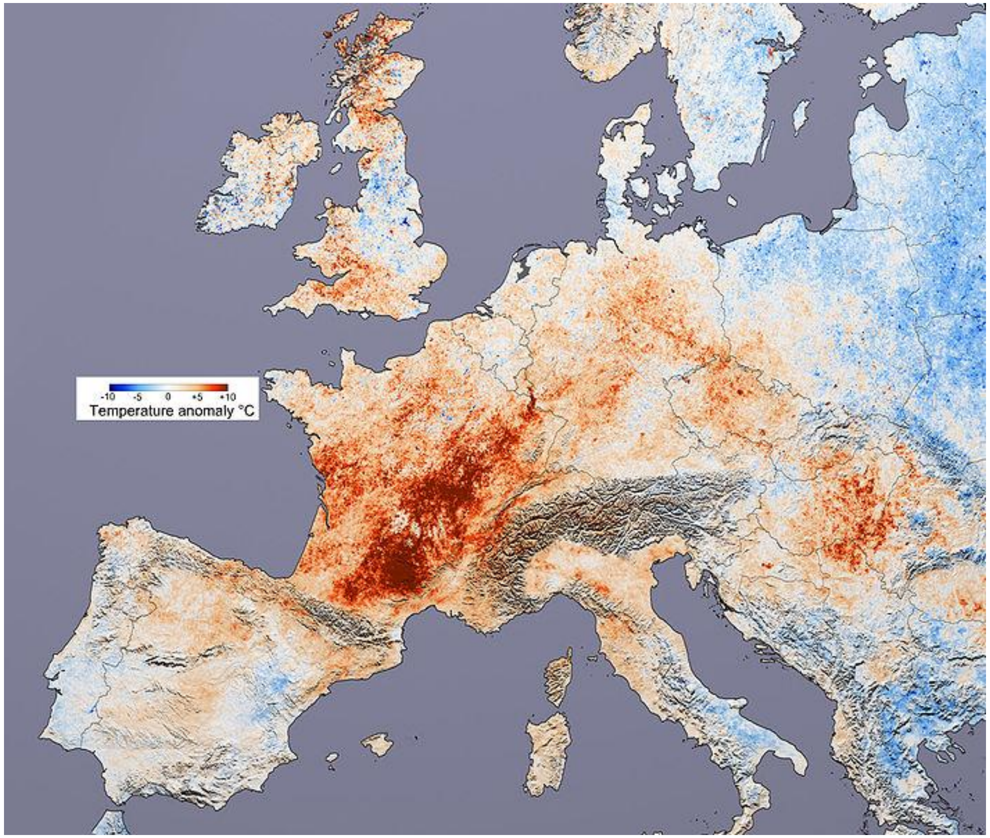


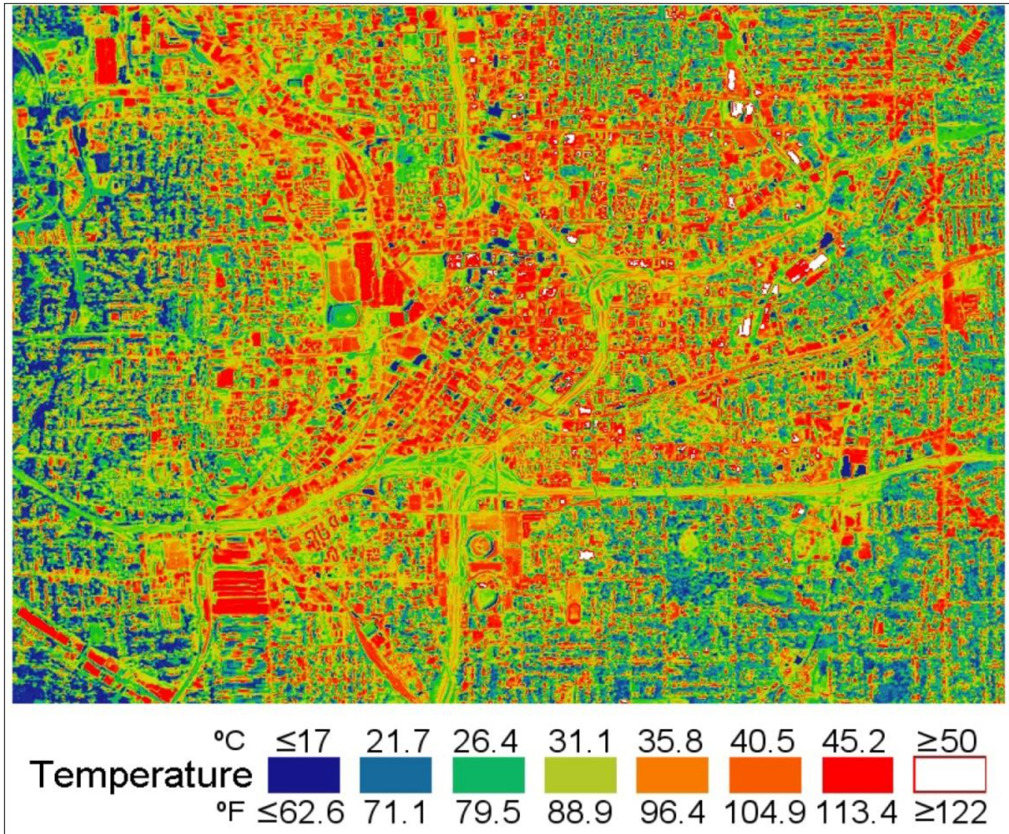
Image: http://en.wikipedia.org/wiki/File:Canicule_Europe_2003.jpg

Why Urban? (Vol 2)

- Urban areas are major sources of airborne and waterborne pollutants and major sinks for materials and energy
  - How do the properties of urban environments modify the flow of water borne pollutants, urban water use and urban energy use?

Image Source: http://www.guardian.co.uk/politics/2007/mar/06/greenpolitics.uknews

Urban Heat Islands



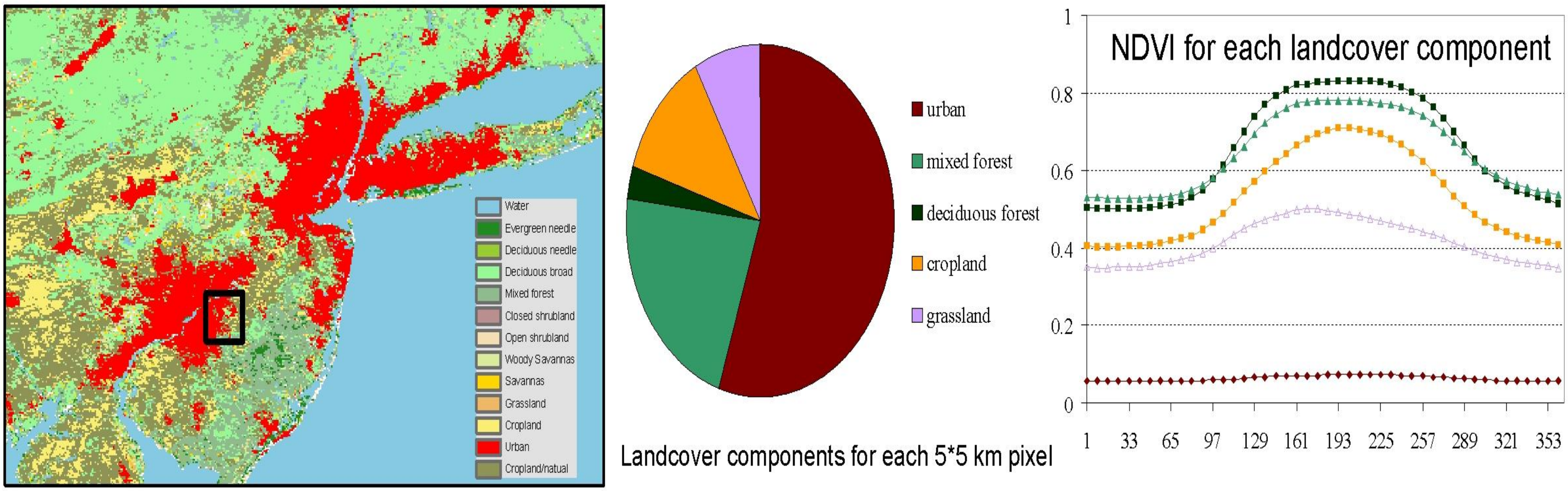
1997 Day time TIR image of Atlanta Georgia
Source: Quattrochi, "HyspIRI Thermal IR (TQ4) Science Questions …."
Image source: Atlas, May 1997

Atlas: 15 channel system
6 TIR, 1 MIR, 8 VNIR-SWIR
http://www.ghcc.msfc.nasa.gov/atlanta/

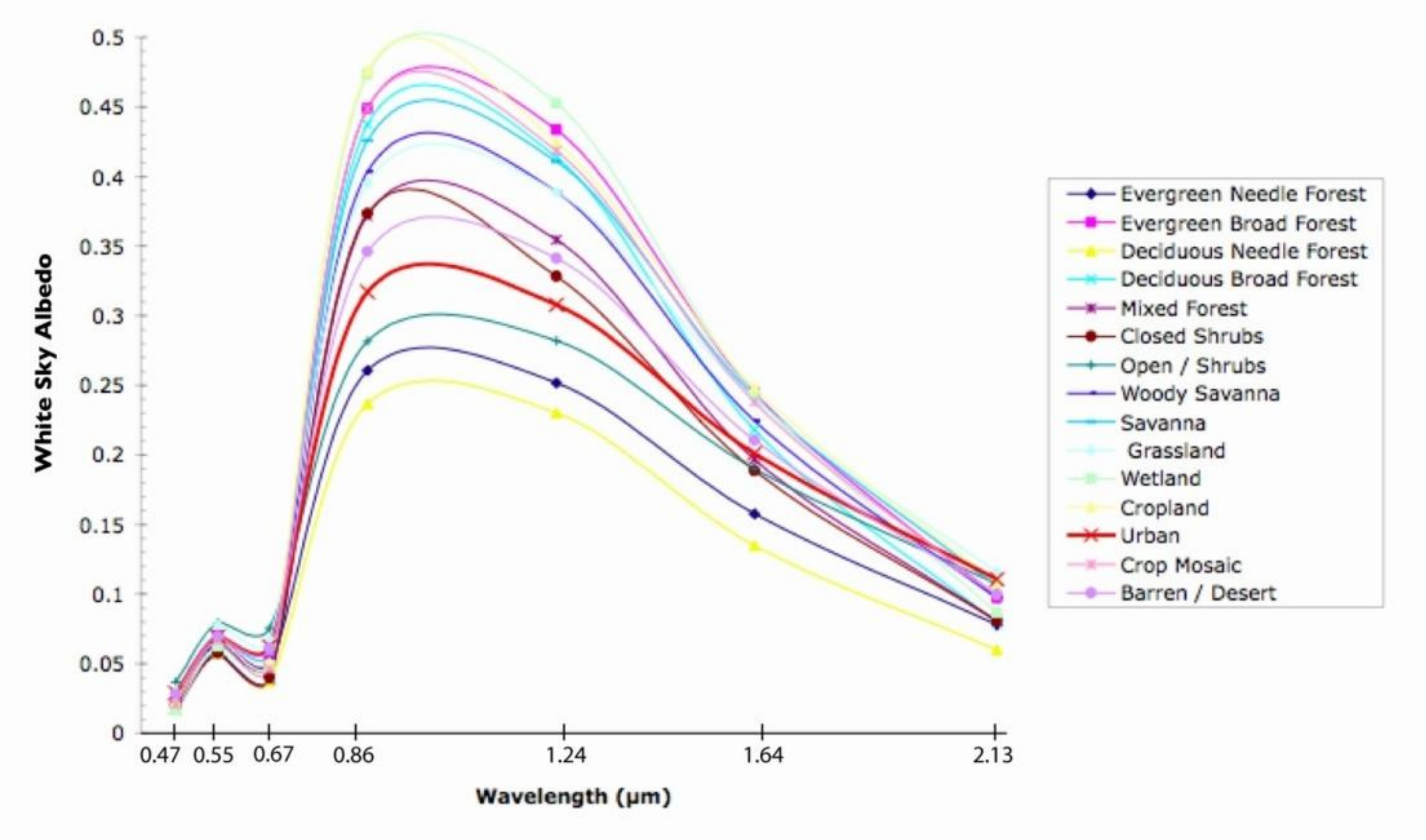
- **Urban areas are warmer than natural areas**
  - **Low albedo surfaces**
  - **Lack of vegetation cover and shading**
- **Urban areas can create their own weather**

Potential HyspIRI Synergies

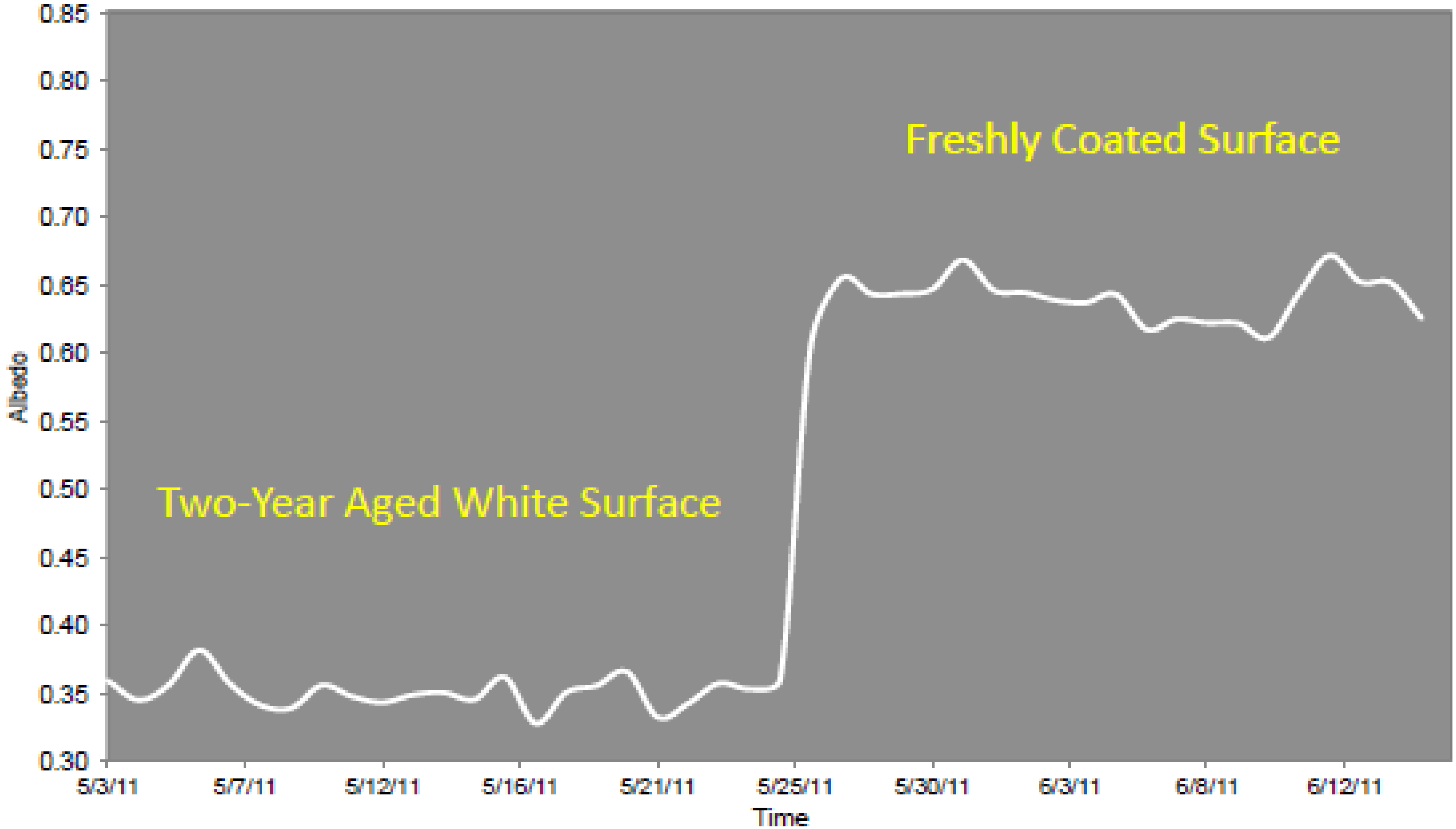
- **Improved Temperature Emissivity Separation**
  - **Water vapor largest error source**
  - **Replace regional column water vapor with VSWIR water vapor**
- **Full characterization of surface energy properties**
  - **Surface albedo, vegetation cover, impervious cover, emissivity, Land Surface Temperature (LST)**
- **Improved discrimination of materials**
- **Multi-wavelength measures of plant stress**
  - **VSWIR biochemistry, physiology**
  - **TIR canopy temperature**



Example of land cover composition and fractional average NDVI



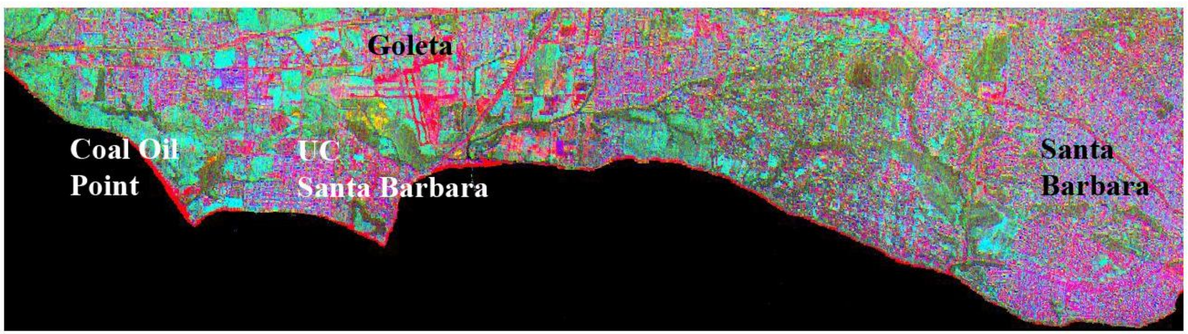
MODIS albedo for late July, 2001 over Chicago for different land cover classes. Urban areas (red) are less reflective than most vegetated surfaces in the photosynthetic region of the spectrum while they are most reflective at longer wavelengths.



Albedo change for a freshly painted white elastomeric paint applied to an asphaltic roof membrane in New York City. This “do-it-yourself” method for raising urban rooftop albedo is the lowest-cost high-albedo retrofit approach available (Gaffin et al, 2011).

Study Site: Santa Barbara

1650, 831, 684 nm: RGB



11.35, 9.1, 8.6 um: RGB

2 km

- **Mixed urban-natural systems, ~ 150,000 people**
- **AVIRIS-MASTER pair, June 19, 2008**
  - **7.5 m AVIRIS, 15 m MASTER**
  - **Spatial degradation, 15 m AVIRIS, 60 m AVIRIS/MASTER**

Methods

- **AVIRIS Analysis**
  - **ACORN 5, applied to 7.5, 15 and 60 m radiance data**
    - **Reflectance, water vapor, liquid water, albedo (Modo 4.3 Irradiance)**
  - **Surface Composition**
    - **VIS Model (Vegetation, Impervious, Soil expanded to include NPV)**
    - **Multiple Endmember Spectral Mixture Analysis**
      - **Fused field and AVIRIS-derived spectral library (7.5 m)**
      - **Count-based Endmember Selection, cover class (i.e., bark, composite shingle, oak)**
      - **Multi-level fusion (2, 3, 4 em models, selected based on 0.007 RMS threshold)**
    - **Water screened by LST (< 297.15K)**
- **MASTER Analysis**
  - **Temperature Emissivity Separation (TES)**
    - **Modtran 5.2 derived atmospheric correction**
    - **NCEP column water vapor, iteratively adjusted for water over Laguna Blanca**
    - **TES, using ASTER algorithm (Gillespie et al.)**
  - **Spectral emissivity, broad band emissivity, LST**

Land-Cover Analysis/Mixture Validation

- **Defined 14 dominant land-cover classes on Google Earth Imagery**
  - **Residential (high, medium, low), Commercial, Transportation, Roofs**
  - **Closed canopy forest, Forested park, Golf courses, Grass sports fields, Orchards, Annual crop**
  - **Bare soil, crop**
- **Extracted GV, NPV, Impervious, Soil fractions and land surface energy properties**
- **Developed Mixture Validation Data Sets from NAIP**
  - **120x120 m polygons (ranges in surface fractions)**
  - **Large, mixed land-cover polygons**

Land-Cover Analysis: Examples

Closed Canopy Forest

Low Density Residential

High Density Residential

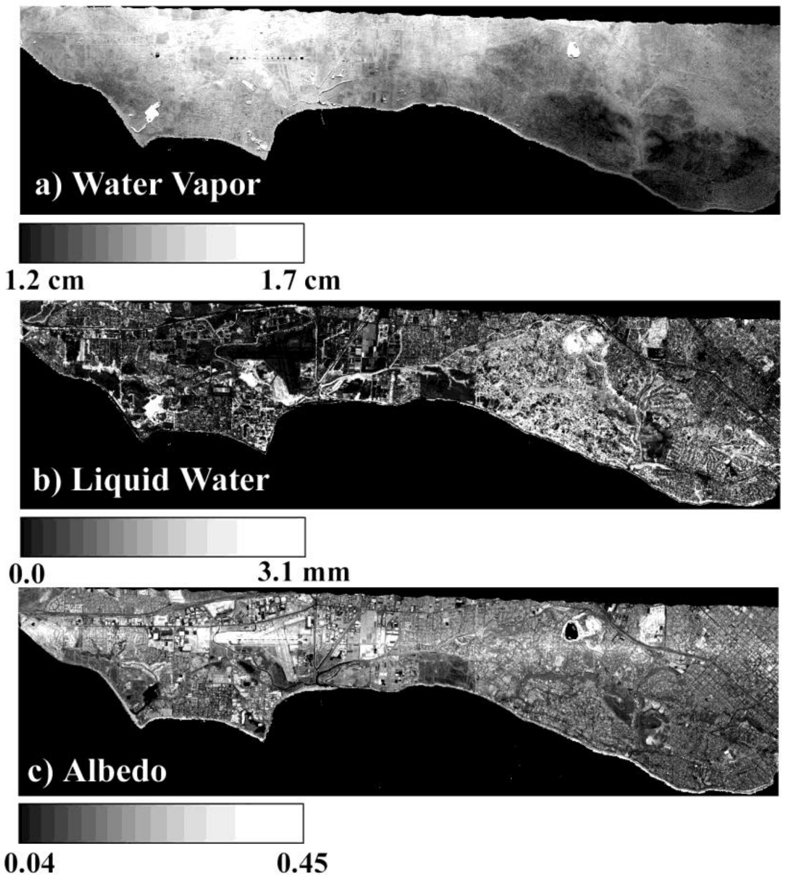
Commercial/Transportation

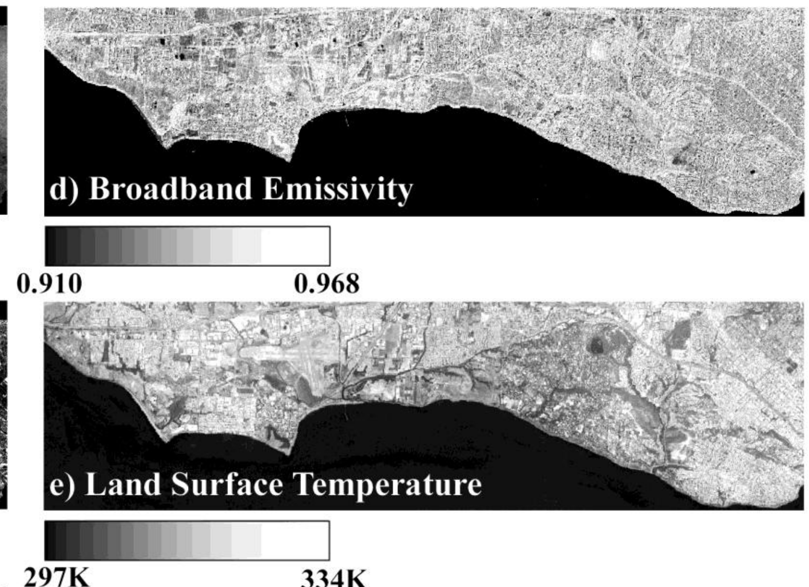
Mixture Validation

- **Utilized 85 polygons**
  - **64 land-cover**
  - **21 designed**
- **Calculated fractions from high-res imagery**
  - **Manually delineated polygons for GV, NPV, Soil and Impervious**
  - **Determination aided by AVIRIS**

Figure showing three validation polygons
A: 44% NPV, 11.3% GV, 44.7% Soil
B: 50.45%NPV, 1.5% GV, 48%Soil
C: 4.8% NPV, 57.4% GV, 34.5% Soil, 3.3% Imp

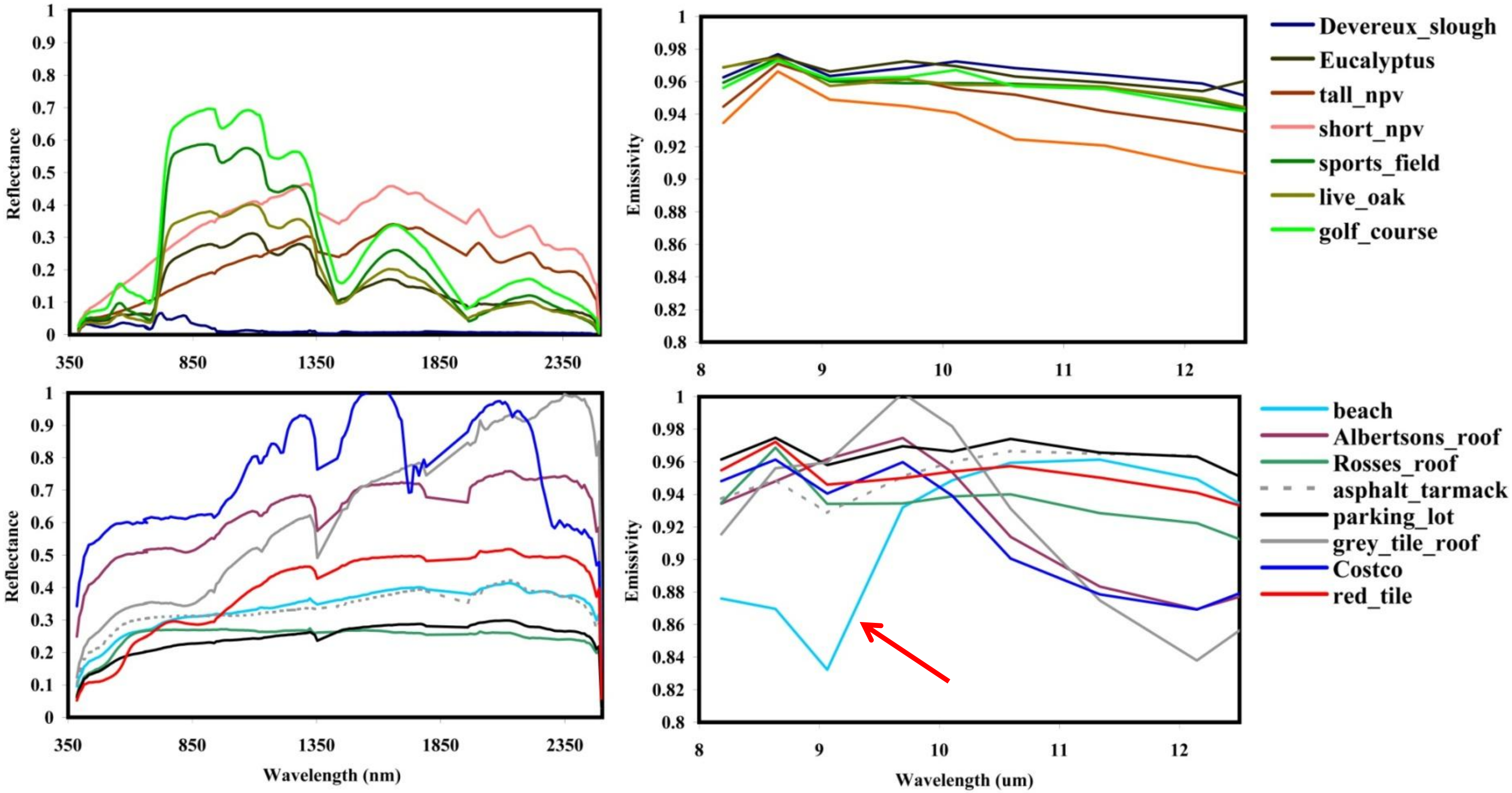
Results
AVIRIS-MASTER Products





- **Fine spatial scale variability in water vapor**
  - **Elevation gradients clear**
  - **AVIRIS 1.2 – 1.7 cm, MASTER 0.78 cm**
- **Liquid water and emissivity positively correlated**
  - **Asphalt also high emissiivty**
- **Albedo and LST poorly correlated**

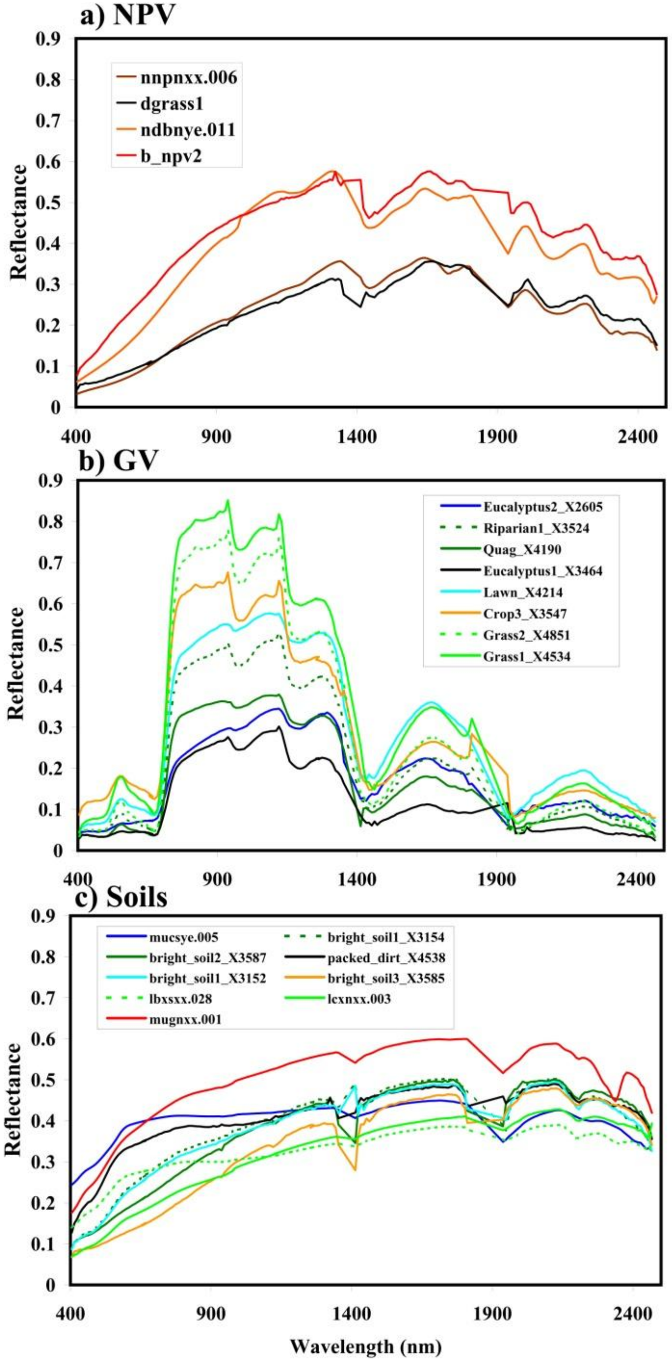
Reflectance and Emissivity Spectra

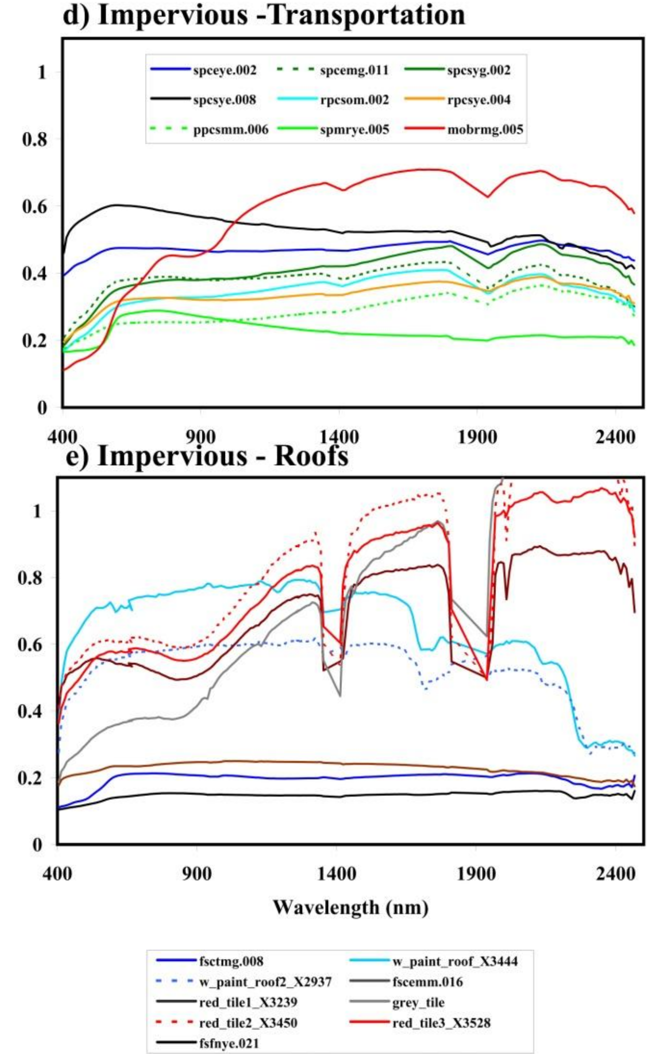


- **Biotic Materials – Most Distinct in VSWIR (all unique)**
  - **NPV low emissivity in TIR (Differs by stature)**
- **Abiotic Materials – Varies**
  - **AVIRIS: Painted roofs, red tile**
    - **Soils and some road surfaces are not distinct***
  - **MASTER: Quartz beach sands, various roof types**
    - **Asphalt surfaces are near black bodies**

VSWIR-TIR improves discrimination of abiotic materials

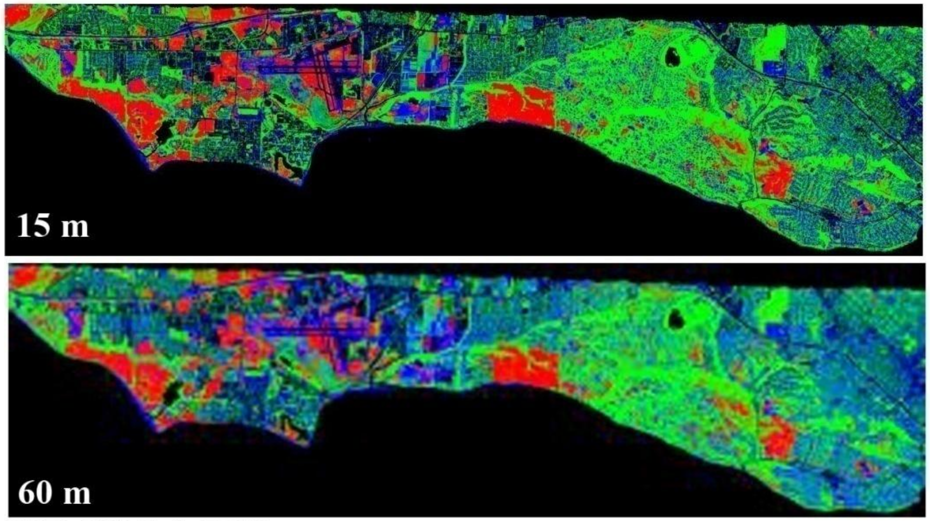
MESMA: Endmember Selections



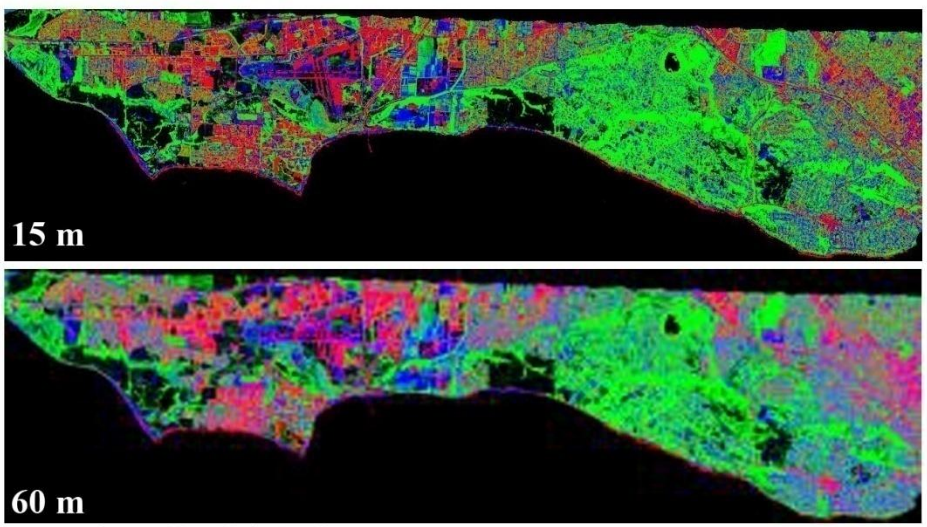


- **Selected 41 non-water endmembers**
  - **4 NPV, 8 GV, 9 soils, 20 Impervious**
- **GV strictly AVIRIS, transportation field, roofs, soils, NPV mixed**

VIS-NPV Fractions: 15 and 60 m



NPV, GV, Soil :RGB

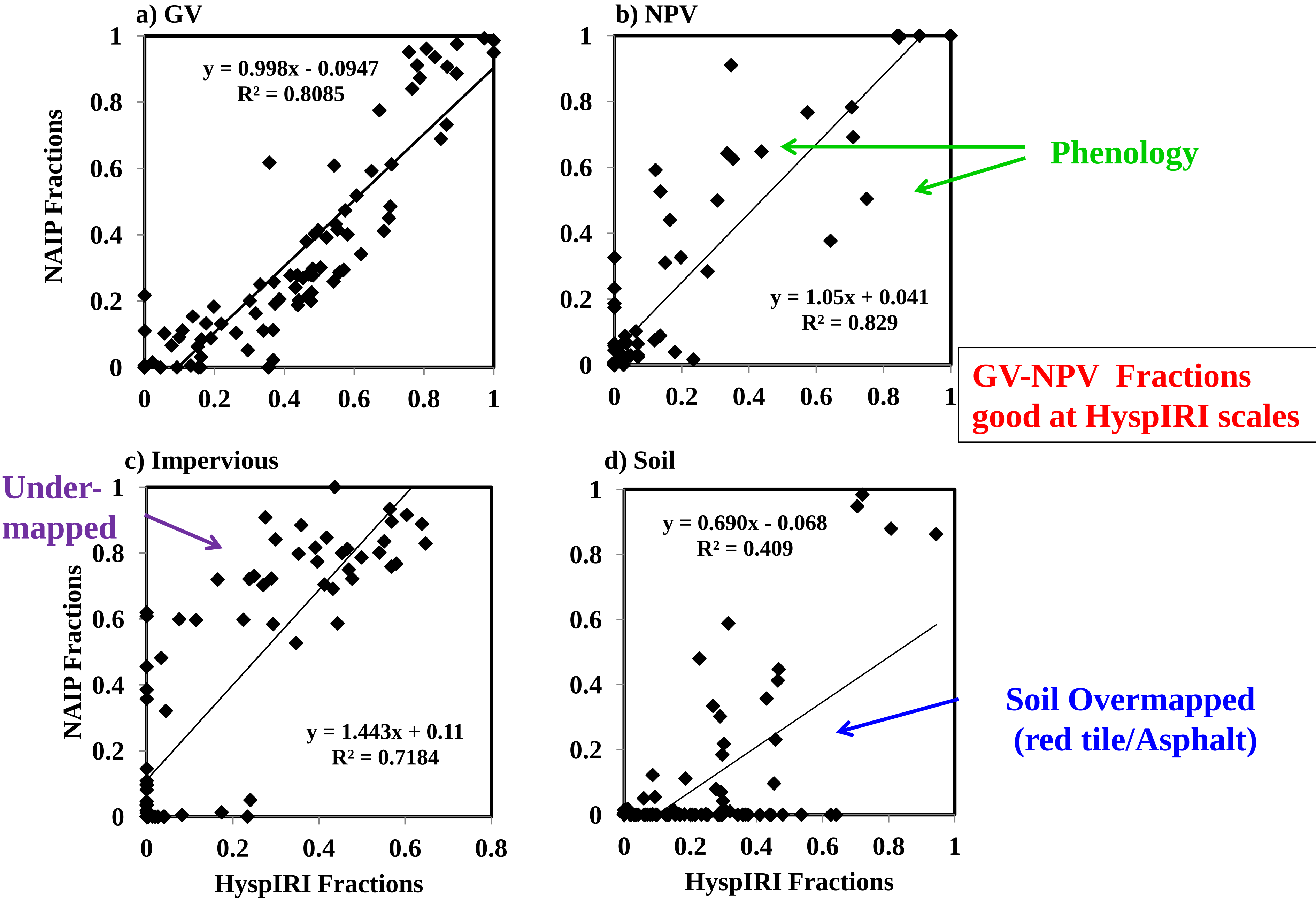


Impervious, GV, Soil: RGB

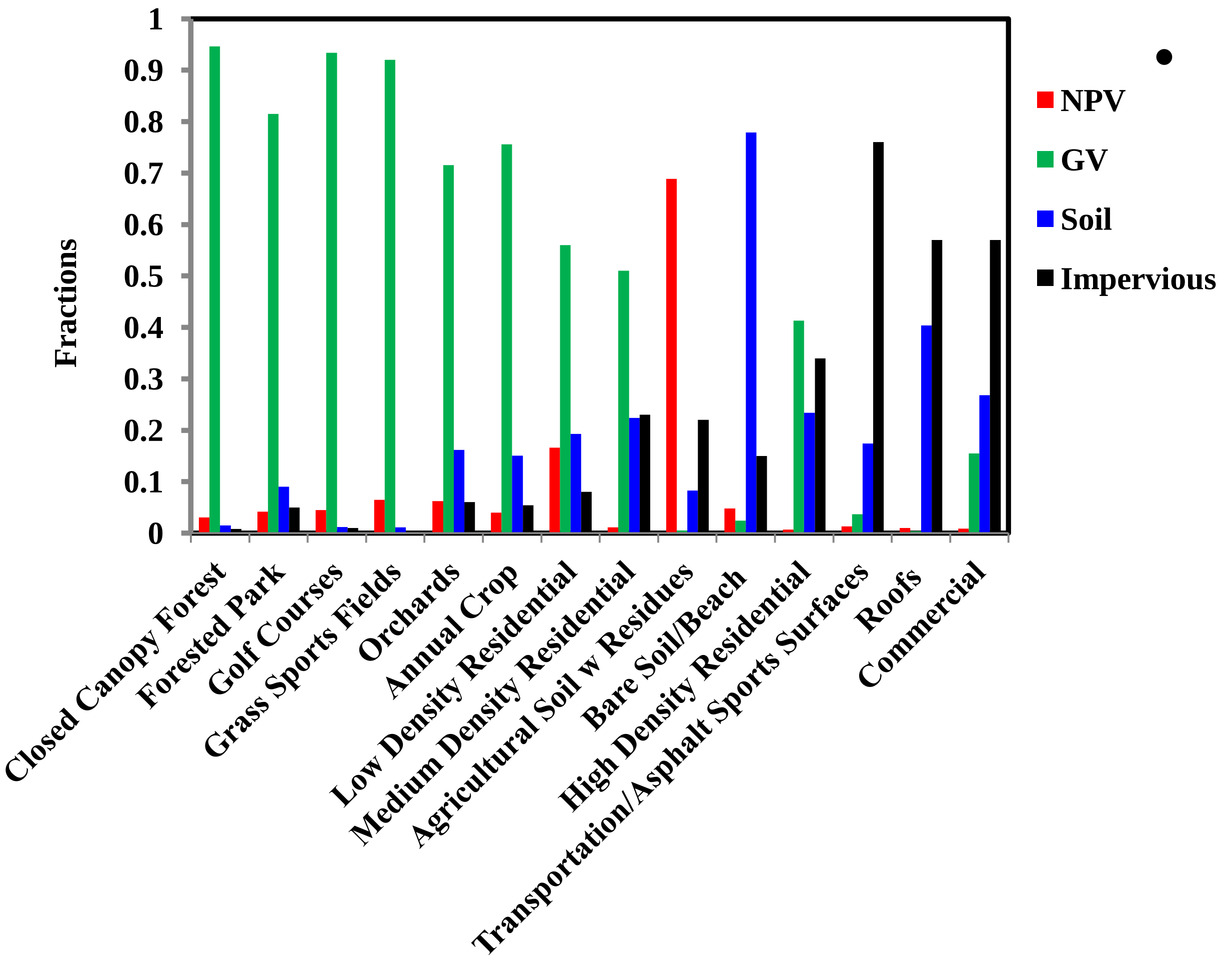
- **GV and NPV fractions scaled well between all spatial resolutions**
  - **7.5, 15 and 60 m**
- **Soil tended to be overmapped at the expense of Impervious at coarser scales**

Two error sources
Asphalt – soil
Red Tile Roof (so variable requires 3 ems)

Fraction Validation: 60 m

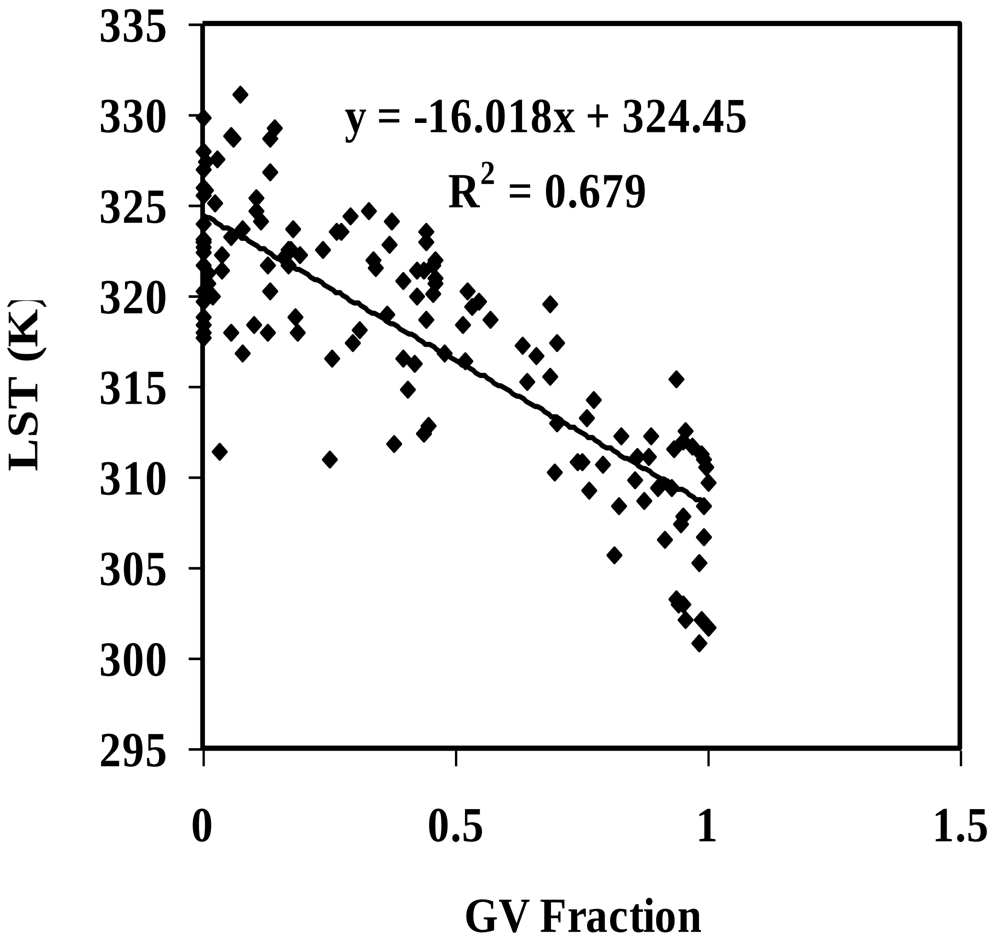


Land-cover Composition



- **Cover fractions follow the expected pattern**
  - **High GV, low Temperature**
  - **High Impervious, high Temperature**
  - **Residential**
    - **Low density, high GV, Low T, low Imp**
    - **High density, low GV, High T, High Imp**

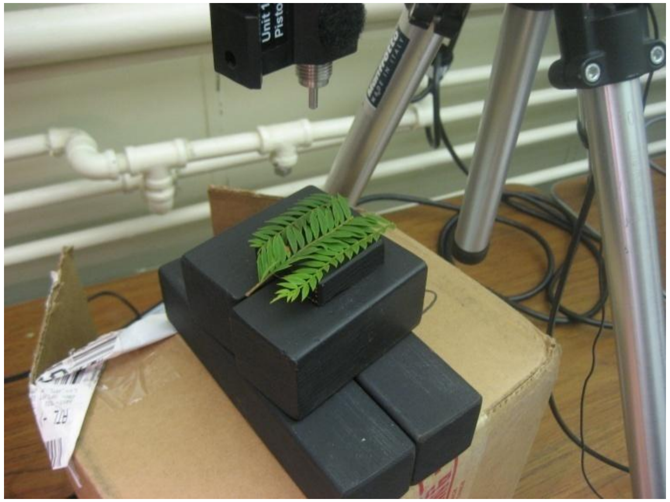
Green Cover and LST

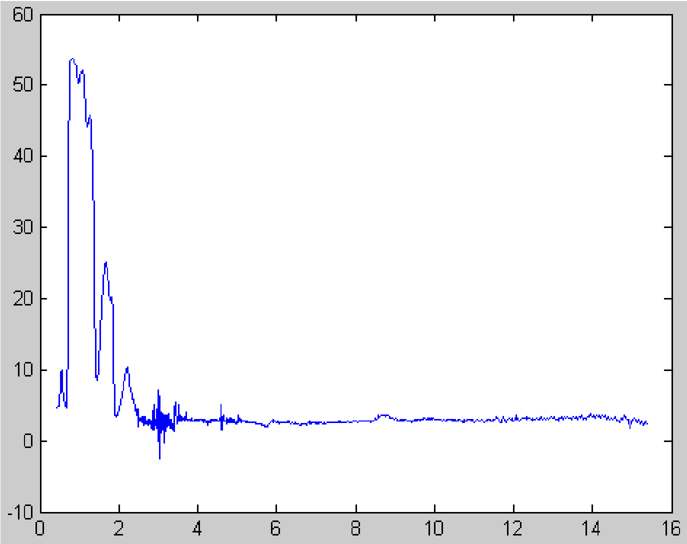


- **Standard inverse relationship between GV Cover and LST**
- **Considerable scatter**
  - **The scatter is likely to be the most interesting part**
  - **Moist soils evapotranspiring**
  - **Closed canopies with variable ET**

What's Next?

- **TES with AVIRIS derived column water vapor**
- **Spatial variation in LST in closed canopies**
  - **VSWIR stress measures**
- **Analysis of new AVIRIS-MASTER pair, 2011**
  - **Greater areal coverage, including greater elevation range, Gap, Tea and Jesusita Fire scars and a wide diversity of natural vegetation**
- **Seasonal VSWIR-TIR spectroscopy**
  - **JPL Perkin Elmer, ASD and Nicolet**
  - **17 tree species, chlorophyll water**
  - **First measures late July 2011**
    - **Follow up, Nov/Dec 2011, Mar 2012, June 2012**





Source: Mike Alonzo, Keely Roth

Summary

- **Urban material Identification will be difficult with HyspIRI**
  - **Variation too fine scale**
- **GV-NPV cover stable at multiple scales**
  - **Impervious can be improved**
    - **Improved Red Tile Roofs**
  - **Potential for VSWIR-TIR unmixing for abiotic materials**
    - **Improved soil-impervious discrimination**
- **Energy patterns reasonable**
  - **GV-LST inversely correlated**
  - **Impervious-LST positively correlated**
  - **Considerable scatter – which is the interesting part**